Application of the SMED Methodology in a Casemaker Production Line

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Master's Dissertation

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Abstract

The present thesis intends to study a cardboard casemaker Production Unit, with the goal of reducing the changeover time.

First, a diagnosis of the changeover processes was performed, in order to understand the associated procedures; to identify problems and to find improvement opportunities.

The project encompassed the several stages of the SMED methodology and aimed at the reduction of the setup time through the analysis and reorganization of the tasks performed in each setup, and through the implementation of equipment-related physical improvements. The SMED methodology focused on enhancing the existing resources, so that no relevant financial investments were required. Organization, motivation and awareness in terms of setup time were the main criteria considered in the design of new solutions.

The application of this methodology in the casemaker's production line resulted in a reduction of the total changeover time in approximately 16%. This translated into a three percentual points increase of the OEE, which reflects into an estimated annual growth in sales of about 105 000 euros.

Resumo

Este projeto de dissertação contempla o estudo de uma linha de produção de caixas de cartão, de forma a reduzir o tempo de mudança de referência.

Em primeiro lugar, foi feita uma análise de todos os processos de mudança da linha de produção em causa, na medida de perceber todos os procedimentos, identificar problemas e encontrar oportunidades de melhoria.

O projeto envolve a implementação da metodologia SMED, cujo principal objetivo é a redução do tempo de setup através da análise e reorganização das tarefas de mudança de referência e melhoria dos processos no equipamento. Esta metodologia teve foco na melhoria dos recursos existentes, o que significa que não houve investimento financeiro relevante. Organização, motivação e consciência do processo de setup foram os principais critérios para desenvolver as soluções.

A aplicação da metodologia na linha de produção de caixas de cartão resultou na redução do tempo total de mundança em 16%. Este valor refletiu um aumento do OEE em três pontos percentuais que, por sua vez, traduz-se num crescimento anual de vendas em 105 000 euros.

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To all the friends who helped to follow my path, with their company in study and fun.

Finally, to my parents, brother, sister and boyfriend for all the support. The patience, friendship and kind words that always have throughout the years.

Ana Mota

"Great things are done by a series of small things brought together."

Vincent Van Gough

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Acronyms and Symbols

KPA	Key Performance Areas
KPI	Key Performance Indicators
OEE	Overall Equipment Effectiveness
PU	Production Unit
SMED	Single Minute Exchange of Die
WIP	Work in Progress
5S	Sort, Set in order, Shine, Standardize and Sustain

Chapter 1

Introduction

1.1 Company Presentation

Europac Group, a multinational company in the packaging sector, specializes in the production of recycled and biodegradable products with natural and recycled raw materials. It is present throughout the whole value chain of the paper industry, from waste management as a source of raw materials, to the production of recycled paper and kraftliner, and the production of corrugated carton and paperboard packages.

It was approximately three years after its set up in 1995 that the company was quoted in the capital markets for the first time. Currently, the company owns about 27 production units and 8.5000 hectares of forest exploration in countries such as Spain, France and Portugal, managing about 2.300 direct employees with an annual turnover of roughly 1.100 million euros. Europac is the only producer of coated paper and kraftliner in southern Europe. Furthermore, it holds the first place in Portugal in terms of packaging production , the fourth in France and in the Iberian Peninsula, where it is also the second in the recovered paper industry .

1.1.1 Ovar's Unit

This dissertation project was developed in Europac Cartão Ovar, one of the production units of Europac Group headquartered in Ovar, Portugal. This production plant is divided in two main activities: **Corrugating** - paperboard production, and **Converting** - transformation of paperboard in carton boxes.

1.2 Framework and Problem presentation

Europac Group has shown a turnover growth and along with it the need to provide the best products to its customers, whilst complying with their requirements, which, in the modern economic reality, are increasingly demanding. Facing the growing competition, it is of crucial importance to always be a step ahead in terms of technology, in order to be able to achieve the highest productivity level possible. This current analysis establishes the operating results as the main focus in the matter of improvement at Europac plants. Thus, the packaging department developed the *Ambition Project* not only with the goal of focusing on the enhancement of the plants' production efficiency but also to strive for innovation in terms of product development and business processes. The Duenas and the Bretagne plants were chosen to be the pilots for this project, from which 27 best practices were identified, associated to 9 KPA (Key Performance Areas), namely waste, planning, line staffing, design office, maintenance, line supply, work organization, converting and corrugator. The project's rollout was put into practice in four other plants and is now planned to be implemented in Ovar.

As far as the Ovar unit is concerned, the focus lies on improving both the production capacity, and the effectiveness and efficiency of the processes. In fact, among the main problems affecting the productivity are high setup times, machine failures and variable process speed. These, in turn, are caused by a poorly implemented working culture. Currently, workers show low ability to analyze and solve quality- and waste-related problems.

1.3 Methodology

This thesis arises from the *Ambition Project* and has the implementation of the lean manufacturing concept as main goal, whilst also looking to improve the existing production processes. The aforementioned implementation process is divided into three macro phases, the first being 1) the analysis of productivity losses, which includes the examination of the three types of losses - MUDA, MURI, MURA; followed by 2) the identification of problems , through the Ishikawa diagram and the "Five Whys" methodology; and finally 3) the implementation phase which includes the SMED methodology and Continuous Improvement concepts. In striving to develop a better and more coherent specialized work, this study focuses solely on one production line: the Casemaker PU15.

The methodology chosen for the conception of this project encompassed a set of steps, which will now be presented in chronological order. At first, a study phase of both the material and the information flows, in which the focal point was understanding the processes and operations of production line 15.

Then a phase of observation and study of the production line took place, with the intent of kick-starting the project framework in the production lines area, by understanding how the process of reference/product switching is carried out and what are the set of activities that integrate it. Subsequently, through the application of the SMED tool, an analysis and an evaluation of the group of activities was performed in order to understand if both the execution's mode and sequence were the most appropriate. For each of the critical problems diagnosed, improvement proposals were developed with the main objective of simplifying and reducing reference changeover time.

Finally, the testing, implementation and analysis of the results for each of the feasible proposals followed. The completion of this improvement project demanded a definition of its execution's mode and sequence, which was only possible through the normalization of the process-related set of operations.

The main objective of this dissertation is to study the implementation of SMED methodology for a casemaker production line. Based on diagnostic's results, develop solutions and obtain a reduction of 10% in total setup time.

1.4 Dissertation Structure

This report is divided into five chapters. The purpose of the introduction is to define this study's objectives and to frame, in general terms, the work done. Chapter 2 includes the state of art and the theoretical framework. Chapter 3 provides a description of 1) the initial situation, 2) the analysis and data collection, and 3) the problem areas to be targeted in terms of the application of the methodology. Chapter 4 deals with the design of the projected solutions and its implementation, with the description of the data related to both the testing and implementation phase, as well as the evaluation of the results obtained. Finally, Chapter 5 presents the conclusions drawn from this project and future work that may be developed.

Chapter 2

Bibliographic Review

2.1 *Lean* Fundamentals

Lean Manufacturing is a production philosophy focused on waste reduction, more specifically, in identifying and eliminating non-value added activities and optimizing the value-added activities, so that resources may be used in the most efficient way. Further along this study, the concept of waste will be more thoroughly analyzed and described.

“The term Lean Management originated from the word leaning; which refers to the reduction of fats from the body in the process of weight reduction and in making one’s body attractively lean and agile." Kiran (2017) The success achieved by Toyota with its Toyota Production Systems that pioneered the Lean practices gave rise to the name *Toyotism*. Toyota Production System is based in two main philosophies: waste elimination and respect for people, in order to achieve the highest quality and productivity (Jacobs and Chase, 2014).

2.2 Waste

The application of a Lean philosophy means eliminating waste. First, however, it is necessary to understand the concept of waste.

Waste is anything that does not add value from the customers’ perspective. Therefore, it has to be eliminated (Ohno, 1988).

There are three big types of waste described in the Toyota Production Systems, frequently called the 3M’s, which describe the expected results of the application of collective practices that generate waste to be eliminated. Those are Muda, Muri and Mura. Toyota has developed its production system around eliminating these three enemies of

Lean: Muda (waste), Muri (overburden) and Mura (unevenness). "...insufficient standardization and rationalization creates waste (muda), inconsistency (mura), and unreasonableness (muri) in work procedures and work hours that eventually lead to the production of defective products (...)", Ohno (1988).

MUDA, in japanese, means waste caused by any activity that does not add value from the customer's perspective. It may be categorized in eight types, seven defined by Toyota, namely: Defects, Overproduction, Waiting, Non-used Talent, Transport, Inventories, Motion and Excess processing, plus the 'non used skills'.

- Overproduction - manufacture an item before it is actual required;
- Waiting - idle time created when material, information, equipment or people is not ready;
- Transporting - Transporting product between processes is a cost incursion which adds no value to the product;
- Too much machining (over processing) - This type of waste usually reflects on doing work that doesn't bring additional value or it brings more value than required;
- Inventories - undelivered products or parts. Overstocking with equipment that may be in need somewhere in the future;
- Moving - This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching;
- Making defective parts and products - broken parts or defected parts that need to be reworked.

MURA stands for variability and irregularity. Unevenness in process times or some other kind of variation.

MURI is defined as the unreasonable burden, for the organization, operators or equipment.

In order to identify waste, its origin must be understood (Ohno, 1988). Following that line of thought, waste was divided into 7 categories:

2.3 Ishiwaka

The Cause-Effect diagram has been proved to be a very important quality tool. Its key function is to identify the main causes that can influence a particular effect. It is mostly associated with failure analysis in equipment, systems or processes.

It is known as the *Ishikawa Diagram*, after its pioneer, the Chemical Engineer Kaoru Ishiwaka presented it in 1943, or as *The Fishbone Diagram*, due to its particular form, presented in the figure 2.1. For manufacturing industries, six parameters were identified corresponding to six possible causes, which are knowns as the 6 M's - Machine, Method, Material, Manpower, Measurements and Environment (Kiran, 2017).

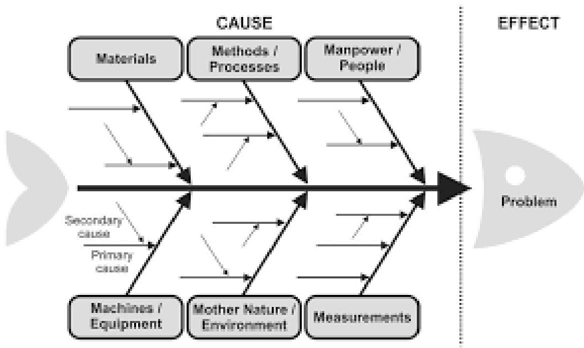

Figure 2.1: Ishikawa Diagram

2.4 Spaguetti Diagram

Transportation, Motion and Waiting time are some types of waste that are commonly found in every process or operation irrespective of the nature of the work.

The Spaghetti Diagram is a tool that helps to identify the waste with regard to transportation, motion and waiting time. It works on the physical layout of a process to achieve its goal. Spaghetti Diagram tracks the movement of products, papers and even people.

It is a visual representation of the physical flow of materials, papers and people through the tasks (or) activities of a process. With it is possible to details the flow, distance and waiting time of the transportation of items in the process. And also trace the routing patterns of people, shuttling back and forth of materials between tasks and work stations.

It looks as messy and complicated like the dish 'Spaghetti', that is why it is called Spaghetti diagram.

2.5 5 whys

The “5 whys” is a very simple but rather effective technique. Its scientific approach is to question in sequence five times “why” when facing a problem. It helps to uncover the root causes of problems. Identifying the root cause of a problem is essential, otherwise problems will keep occurring and may eventually get worse over time (Ohno, 1988).

2.6 OEE

The acronym OEE stands for Overall Equipment Effectiveness and emerges as a powerful tool to analyze the efficacy of a production system. The main idea of this indicator is to measure the percentage of planned production in which the system is really productive. It functions as an important KPI, which makes the companies examine all the performance aspects of a production system to make sure they get the most out of it. More than a simple KPI, OEE identifies the main problems to be solved first (Inc., 2017).

The calculation of OEE (see equation 2.1) is carried out taking into account 3 essential components: availability, efficiency and quality, according to the following formula:

$$OEE = Availability \times Performance \times Quality \tag{2.1}$$

Availability: time in which the production system is planned to be operational, but it is stopped. Loss of availability can be considered as downtime, which means equipment failure, lack of materials and tools or product exchange that requires the stoppage of the machine (setup time and adjustments), (see equation 2.2).

$$Availability = (Time\,available\,for\,production - downtime)\ /\ Time\,available\,for\,production \tag{2.2}$$

Performance, see equation 2.3, reflects the time lost due to the influence of factors that cause the system operating below the maximum speed, such as:

- Micro-stoppages - temporarily interrupted production;
- Speed losses - when the production system does not operate at the maximum theoretical speed due to poor handling of processes or inefficient equipment.

$$Performance = Actual\ production\ or\ capacity / ideal\ production\ or\ capacity \tag{2.3}$$

Quality (see equation 2.4): time when the production system is producing non-conforming products. This can be because:

- Loss on start-up: occurs when equipment is started, while the production system has not yet stabilized

$$Quality = (Total\ quantity\ produced - quantity\ out\ of\ specification) / Total\ quantity\ produced \tag{2.4}$$

Figure 2.2 summarizes the concept.

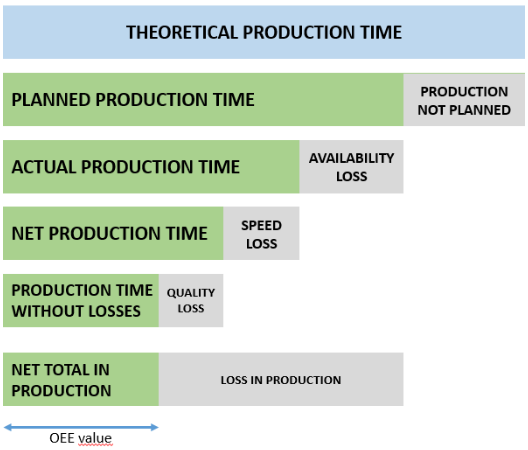

Figure 2.2: OEE

2.7 SMED

Manufacturing processes can be divided into four phases:

- Processing: assembly, disassembly, alteration of shape or quality.
- Inspection: comparison with a standard.
- Transportation: change the location.

- Storage: a period of time during which no work, transportation, or inspection is performed on the product.

Production activities comprise the processes and the operation, and setups are part of each type of operation. The change of products, tools or adjustments made during the process is usually referred to as setup or changeover. During the setup, the process does not generate value, moreover the cost increases and production time decreases. When the cost or setup time is high, the companies usually opt for bigger batches and the resulting investment in stock is high. This way, reducing setup time means saving in costs and enabling the possibility of producing in small quantities (Sabadka et al., 2017).

A very popular lean manufacturing tool which has shown good results is SMED. SMED is the English acronym of Single minute exchange of die (Change of series in less than ten minutes), also called “Quick Changeover”. It was developed by Shigeo Shingo, in the 1960’s, and improved after the following challenge was presented to him by Toyota: to reduce the time of change of a tool in a 1000 ton press that initially took four hours. Unsatisfied with this time, Toyota aspired to reach the 3 minutes mark. The dimension of the task created quick changeover practice focused on time reduction and in the simplification of processes. The possibility of accelerating setups, as well as the economic benefits resulting from an increased due time, and the reduction of workforce-related costs , allows an increase of the setups frequency. In fact, a long setup time forces the machine to work a very long time in order to make the operation profitable. The immediate results of reducing batches are stock reduction and the corresponding WIP (Work in progress). Furthermore, it becomes easier for the operation systems to respond to the demand and to achieve the desired quantities, whilst reducing lead time and reinforcing flexibility.

The improvement of quality and the reduction of losses both result in nonexistent finish goods stock and, consequently, in a decrease of the risk of obsolescent production. The need to reduce production time implies that there must be no errors and consequently that the first product is well produced. That’s why it is necessary to eliminate adjustments occuring at the beginning of a series, and scrap, until the equipment is ready to produce (Shingo, 1985).

The application of SMED Methodology created very good results in several different industrial applications (Shingo, 1985). In particular, in a carton box company, the application of this method has been proved to reduce setup time by 47% (Roriz et al., 2017).

2.7.1 Method

The SMED method was developed and divided in 4 Stages.

Preliminary Stage: internal and external setup cannot be set apart. The preliminary stage only provides the initial time parameters for the activities performed during the setup. In order to obtain the activities' time intervals, it is highly recommended to use a stopwatch, to study the method, to interview the operators and/or to analyze the footage of the operation. The author also indicates that "[...] informal observations and discussions with workers are usually sufficient". According to Shingo (1985) it would be important to differentiate the several types of setup, according to the product and its requirements. It is not considered appropriate to set a fixed general setup time, without taking the type into consideration (Sugai et al., 2007). As an example, if the standard time is defined based on a quick changeover, it may generate frustration within the team to constantly perform over the stipulated time while performing a more complicated setup. Opposingly, if the timecap definition is based on a longer setup, workers may not employ their best efforts in completing the task as quick as possible.

First Stage: Separating internal and external setup. The first phase corresponds to the classification of the activities, its sorting and respective segregation into a)internal setup, namely those activities performed while the machine is stopped, and b) external setup as the activities carried out whilst the machine is working. This is considered to be the most important stage (Shingo, 1985).At this stage, time reductions of 30- 50% can be achieved without extra monetary investments, since the changes are solely related to the organization and coordination of work.

Second Stage: conversion from internal setup to external setup. Reorganization of the operations is required, with the goal of converting internal activities into external, it is necessary to adapt in order to execute it with the machine working.

At this stage it is important to think creatively trying to understand why each activity exists and how these activities can be performed either before the machine stops, or after resuming its operation. A recurring example is components that need to be heated before being assembled into the machine. This heating that was previously done with the machine stopped, can be done with an auxiliary device before the setup begins, allowing therefore a much faster assembly.

Third Stage: Systematic improvement of each basic operation of internal and external setup. The final phase was named "streamlining all aspects of the setup operation". The single-minute strive may not have been achieved in the previous stages, meaning that continuous improvement of each element, both internal and external setup may still be required (Shingo, 1985).

Aiming at improving internal activities, SMED Methodology mentions 3 practices that will aid in achieving this goal. The first practice is establishing parallel activities, by combing tasks that allow a reduction of the work load, by improving the changeover. Nonetheless, its planning must be done carefully, in order to avoid waiting time. “Indeed, a poorly conceived parallel operation may result in 110 time savings at all. (. . .)”, Shingo (1985). Furthermore, there should be an increased focus on safety , since simultaneous work may lead to an increased risk of work accidents.

The second practice is the use of functional clamps. Such a simple change may reduce time, since it achieves the purpose of tightening the clamps with less rotations.

Last is the elimination of adjustments. In most cases, adjustments are necessary due to inaccurate centering and measuring at the beginning of the setup. “It is extremely important to recognize that adjustments are not an independent operation. To eliminate them, we must move back a step and improve the earlier stages of internal setup. (. . .) Eliminating adjustments requires, above all, abandoning reliance on intuition in setting machines for production. Intuitive judgments may have some sort of statistical validity, but they remain inexact and do not have the same precision as constant value settings” Shingo (1985)

These four stages can be converted in seven elementary tasks to reduce setup time.

1. Identify and separate setup activities into internal or external.
2. When possible, convert internal activities into external
3. Eliminate the necessity of adjustments by process, tools and procedure
4. Standardization
5. Improve manual operations by training and practice
6. Improve equipment
7. Create an improvement graph to monitor the results and congratulate the work team

This is the last stage of the SMED implementation, which seeks to reduce the duration of all activities, both external and internal. For this purpose, work standards should be created to avoid wasting time on journeys and waiting times. It is at this stage that the main investment needs are expected to arise since it is at this point that the automation of tools and tasks gains special relevance.

Enhancements in transport and storage of tools lead to an improved workplace organization which subsequently contributes to the reduction of the external setup time. A reduction of the internal activities' time intervals requires the establishment of parallel activities, such as increasing the amount of workers involved in the set up operation, which will enable a decrease in work load to the other operators, accelerating therefore the change of tools. The replacement of the threaded fastenings by functional clamps may also a be a way to reduce the internal set-up time, since these ensure a secure attachment of the tool with a reduced number of rotations.

2.7.2 5S

The 5S concept is the foundation for all improvements and is the key component for establishing a Visual Workplace. Both are a part of Kaizen — a system of continuous improvement which is part of lean manufacturing. It is a simple tool for workplace oganization in a clean, efficient and safe manner, in order to enhance productivity, visual management and to ensure the introduction of standardized working.

5S stands for Sort, Set in Order, Shine, Standardize and Sustain.

***Seiri* - Sort** - in the first 5S implementation phase in which all unneeded tools, parts and supplies are removed from the area, after examining the whole workplace environment and identifying what is really necessary and what may be discarded. This allows for the creation of space in the workplace and eliminates time wasted in looking for tools.

***Seiton* - Set in Order** - A place for everything and everything is in its place. Organizing the way things are put away with efficiency, quality, and safety in mind. There is the need to decide where and how things should be put away and what rules should be obeyed to ensure its maintenance.

***Seiso* - Shine** - The area is cleaned as the work is performed. Sweeping, scrubbing and cleaning of the building, machines, fixtures and tools so that all areas of the workplace are neat and tidy. This leads to early detection of mechanical problems before they become major breakdowns.

***Seiktsu* - Standardize** - Cleaning and identification methods are consistently applied. Ensuring that each workplace is properly designed for safety. This is to protect every member from the possible dangers that may arise during the performance of their assigned tasks.

One of the most relative variables is human force. As widely known, human nature is undeniably associated with error. Therefore, in order to keep efficiency by eliminating defective products, operational mistakes and accidents, the standard sheet can be considered a very helpful tool.

The standardization of work is of utmost importance as it allows the workers to better understand their job and assigned tasks, its sequence and respective time frames/deadlines. As such, the standardization's 3 main elements are takt time, work sequence and standard inventory (Ohno, 1988). The takt time is the time to produce 1 unit.

Standardized work provides a stable foundation for building all other improvements through the implementation of the Lean Tools, while also providing a highly visual workplace. One of the most important factors of 5S is that it makes problems obvious immediately. 5S is a team-run process and should be conducted by the people who work within the area in which the principles of 5S are being applied.

Shitsuke **- Sustain** - 5S is a habit and is continually improved. It is crucial to develop the practice necessary to consistently participate in the 5S process. This requires that each of the S becomes a personal habit. It is the most difficult of the 5S, but it is also the most important factor in achieving long term success. Establishing routines and procedures of audit, in order to verify compliance with the standard. (Kiran, 2017)

As aforesaid, besides separating internal and external activities, it is also important to improve tasks by reducing their time. If the focus is only on SMED methodology the results can be poor (Sabadka et al., 2017). Therefore, if all tools necessary for the setup are in perfect condition, in the right place and closer to the location where they may be needed, time will be saved. Furthermore, if the operator knows exactly how the setup should be done, the order of the activities and which operator is to perform it, the process becomes faster and more efficient. It is clear that a clean workplace allows fora better perception of what it is going on, as well as for the identification of necessary adjustments or tools.

For the above mentioned reasons, the 5S is the perfect tool to complement SMED Methodology and help on achieving shorter setup times.

Chapter 3

Initial Situation

3.1 Paper

Paper production is the core business of the Europac Group and, in Ovar's production unit it stands as the main raw material, therefore the importance of looking deeper into the subject of understanding the several different types of paper.

Kraft is the virgin fiber paper, which means the fibers are intact, and it is subsequently considered superior in all aspects. The raw material used to manufacture this paper is composed of 80% pine and 20% eucalyptus. It has high resistance in terms of tearing, stress and punching. It also performs better with regard to absorption, which in turn means higher printing quality. Kraft comes in two colors, white or brown.

TestLiners is a type of paper made of recycled fibers. It presents a number of impurities and it is therefore less resistant. There are various types of recycled paper that differ according to cleanliness, uniformity, smoothness and porosity. As with kraft paper, recycled can be white or brown.

Another kind of recycled paper is fluting, which is produced through a process that gives it its corrugated texture, providing it also with cushioning properties and rigidity. It is the paper which is commonly used in the creation of the wave which the cardboard consists of.

3.2 Cardboard Production

Cardboard is a complex product, composed of several flat sheets of paper, the covers, and one, two or three fluted sheets, also known as the waves. The complex is assembled with glue and each component has its own function. The Covers are responsible for the cohesion and resistance of the cardboard, necessary to protect the packaging content. The

Waves ensure the rigidity and allow to sustain the load while it is piled up. Glue ensures the assembly with the other two components. There are several types of waves that differ by the height of the undulation.

The Ovar production unit produces five types of cardboard, namely : E (micro) with 1.7 mm wave height, B (thin) with 3mm, C (large) with 4 mmm, EB (microdouble) with 5mm and BC (double) with 7 mm. E, B and C are named simple and EB and BC double. The following figures 3.1 and 3.2 illustrate the simple and double types.

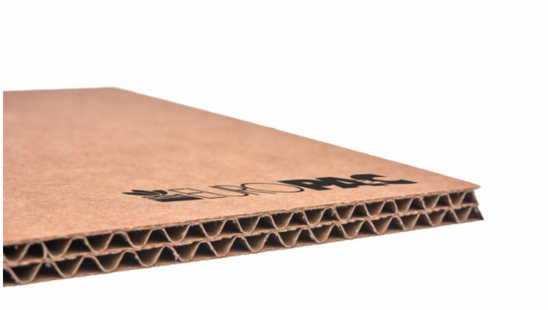

Figure 3.1: *Double Cardboard*

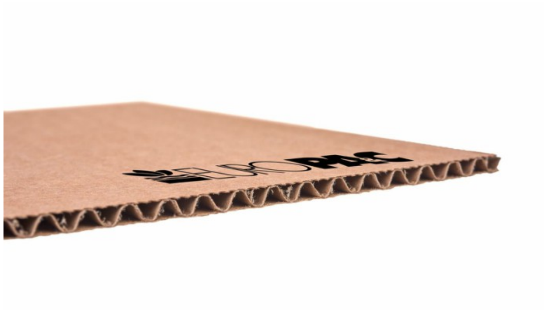

Figure 3.2: *Simple Cardboard*

Following its production, the cardboard is either set for expedition as a finished product, or it may proceed to the transformation facilities as a work-in-progress product. In the transformation, cardboard is converted into carton packages.

With regards to the packaging, two main product groups may be identified; american boxes and special boxes. The first refers to the model (shown in figure 3.3), where only the dimensions may vary. There are production units who specialize in the production of this kind of package, also known as casemakers or slotters. The casemaker glues the box while the slotter does not. In addition, a mold may be added in order to add a variant, for example a hold, or to design a perforated box. The complete production of the special box shown in figure 3.4, requires the use of a mold hence their name cropped boxes.

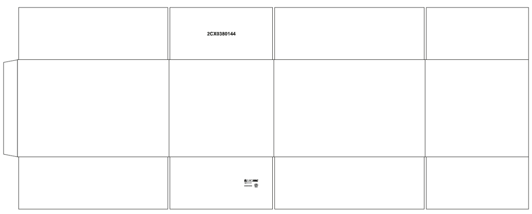

Figure 3.3: *American Box*

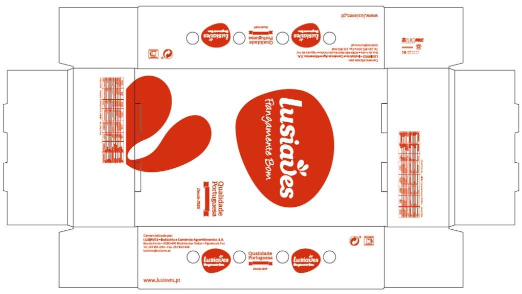

Figure 3.4: *Cropped Box*

The main transformation units are casemakers, slotters, die cutters and closing machines (glue and staple). Almost all casemakers and slotters are able to print.

3.3 Data and Information Systems

The company uses two information systems namely Pc-Topp ® and SAP ®. Pc Topp ® deals with everything related to planning and production management. For example, it shows in real time which reference is being produced in every machine and it is the tool used for operators to start the production of a new reference, to check parameters as well as quality. It also has a statistics tab, where several reports about each machine individually may be downloaded from, or about the plant in general.

SAP ® stands for Systems, Applications and Products. It is a type of ERP (Enterprise Resource Planning), is a resource planning software, integrating business operations, procurement, manufacturing, sales, finance, service and HR. SAP ® and Pc-Topp ® are linked with each other. For example, an order is created in SAP ® by the commercial department and it is then transferred to Pc-Topp ® for the planning department.

With the goal of understanding the initial situation of Production Unit 15 an analysis was made based on two sources. The first data source included data collected from both softwares Pc-Topp ® and SAP ®, while the second involved the monitoring of the production line for a better understanding of the process and to interpret data through the observation and timing of several setups.

Regarding the download of data, a yearly analysis of 2017 was made in order to learn the machine behaviour throughout the year and to identify the main improvement areas. The dimension of the a data sample makes it possible to understand aspects such as seasonality and patterns, and consequently to draw more realist conclusions.

In a second phase, the focus was on the machine state, the frequency and typology of processes, and, for that, the first trimester of 2018 was analysed.

3.4 Production Unit 15

In this sub-chapter the data related to the initial situation of the company in the year of 2017, mainly concerning activities directly and indirectly linked to setups, is presented. This initial work served to characterize the setups generically and to detail all procedures used for to enabling a better analysis

The Production Unit 15 is a Piemonte 2400, installed in 1990. It is a casemaker, which means it prints, marks crosswise, slotters and glues. The slotter is the element that allows the conversion of a marked cardboard into an american box. This unit has a maximum cardboard capacity of 2400 mm of length and can print up to four colors. The initial composition included three color modules only, but since there is a twin machine (PU 14), it is also possible to transfer an extra colour module from the twin machine. In addition, it has a die cutter used, for example, to add handles.

The process begins with the cardboard manual feeding. In the machine, the cardboard passes through one, two, three and four print modules. Each module provides the use of one colour and requires a stamp (one stamp for each colour). The next station is the slotter module, which is responsible for the box shape. The cutting tool responsible for the grooves, is incorporated in the machine and is automatic, provided only that the correct parameters are previously set. The tab cut utilizes an exchangeable tool, which works according to the type of corrugated paper. The Die Cutter module requires an exchangeable mold, in order to reproduce a small cut. Following, there is the bridge, which is where the cut cardboard is closed and glued, becoming ready to unfold and to become a box. The Tying area, where the boxes are separated in the quantity specified to be tied in the wrapper comes next, followed by the final process of palletization, which is also manual and consists of placing the boxes in the pallet.

3.4.1 Demand

The demand in square meters per month of PU15 is described by the figure 3.5. It is used square meters and not number of boxes to observe demand, because the size of the box can vary a lot and so, the number of boxes would not correctly reflect the performance of the PU.

The chart shows that demand is stable along the year, with an average of 580 000 m^2 produced per month, despite some variations. Specifically, the most considerable decrease took place in August and December, which may be explained by the fact that, in these months the plant is closed down for holidays.

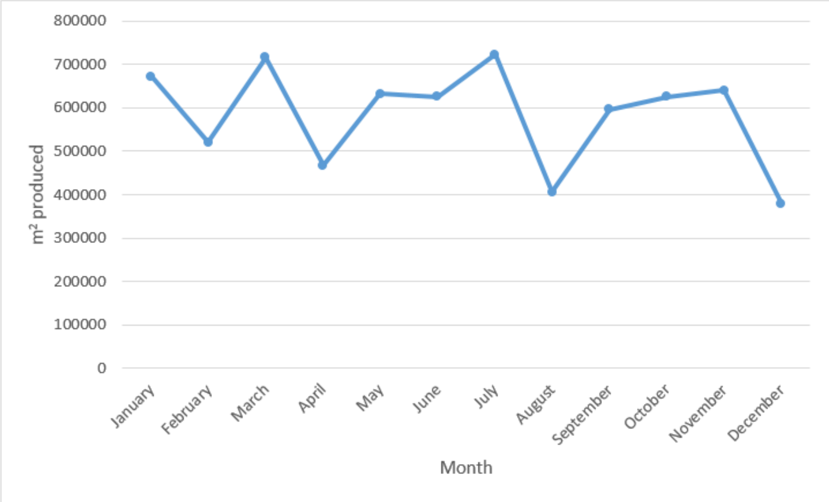

Figure 3.5: Demand PU15

3.4.2 Type of Order

The information for an order includes 1) type of cardboard, 2) format of board (length and width), 3) the mold, 4) number of colours, 5) quantity, 6) tab, 7) amount tied, 8) type of pallet and 9) amount of the pallet. Thus, several different types of combinations are possible. In fact the PU15 is able to produce up to 1800 different references.

3.4.3 Teams

The PU 15 works under a regime of continuous work, divided into three shifts of eight hours each: from 6am to 2pm (morning shift); from 2pm to 10pm (afternoon shift) and from 10pm to 6am (night shift). In each shift, workers have two intervals of 15 minutes. Consequently, PU 15 has three teams, composed by three elements each, more specifically one operator and two assistants. The operator is responsible for the machine, and he/she is the responsible for setups, controlling the orders, its parameters and specifications, and for assigning tasks to the other two team members. The main task of the entrance assistant is to feed the machine with cardboard, while the main task of the output assistant is the palletization. Additionally, both will follow all instructions provided by the operator, and they play a very important role during the setups.

3.4.4 KPI

In order to understand the state of the production unit and its evolution throughout the implementation of the project, it was selected OEE and Productivity for measuring manufacturing productivity. Nonetheless, for a deeper understanding, production speed and stops were selected, since they have a direct influence on productivity. The conclusions about these indicator were obtained through the analysis of data of the year of 2017, provided by Pc-Toop ®.

3.4.5 OEE

The indicator OEE allows an overview on availability, performance and quality. The period chosen for analysis was the year of 2017. The indexes are automatically calculated by Pc-Topp ®, that creates an Overall Equipment Efficiency Report (Appendix A.2). Where Availability is calculated as the ratio of run hours to work hours; Performance as the ratio of actual run speed to target speed; and Quality is calculated as the ratio of well-produced quantity to total produced quantity

The following figure 3.6 exposes the evolution of Availability, Performance and Quality over the months.

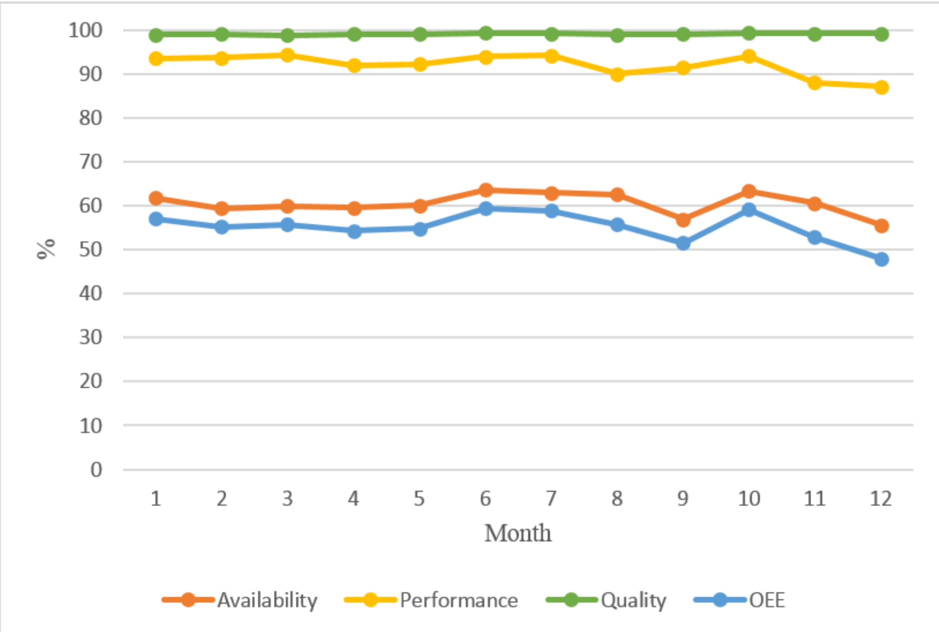

Figure 3.6: Quality, Performance, Availability and OEE

Quality index presents an average of 99%, which is considered very satisfactory. In fact, almost all non-conforming products arise from the initial adjustments when initiating a new order.

Likewise, performance has a high value of, in average, 92%. Regarding PU15, performance losses are caused by micro-stoppages and speed losses, representing, approximately, 82% and 17%, respectively.

However, Availability is the main concern. This index has an average of 61%, which means that 39% of the time available for production is downtime. In order to better understand the low value of this index, the availability losses were analyzed. For this, the data of another report provided by the information system – the Downtime Summary Report of 2017, was analized.

The figure 3.7 presents the distribution of availability losses by its causes.

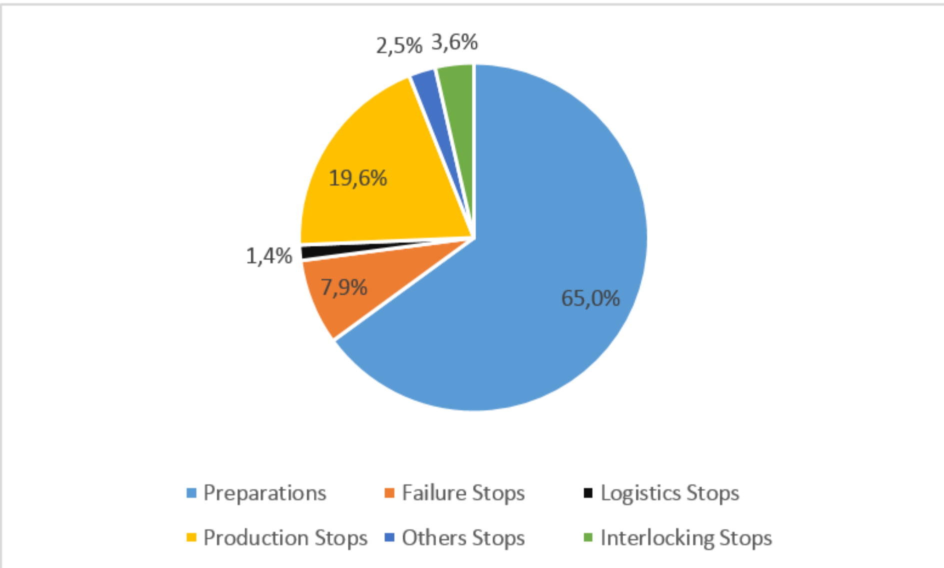

Figure 3.7: Availability losses

It can be concluded that the main loss is due to the preparation time and the rest of downtime is caused by stops.

The information about stops is very important in order to determine the causes of inefficiency and consequently to be able to eliminate them. The full cooperation of the operators is required for establishing the reasons why stops occur. In fact, When the machine stops for longer than 1 min, the information system requires the introduction of information about the stoppage for which the operator must select from a predefined list. When a specific cause is not part of the list, the operator must identify it via special comment inserted in the “other causes” tab.

Among the many possible causes associated to unplanned stops, failures and production stops are the most prevailing ones, as shown in the bar chart 3.8

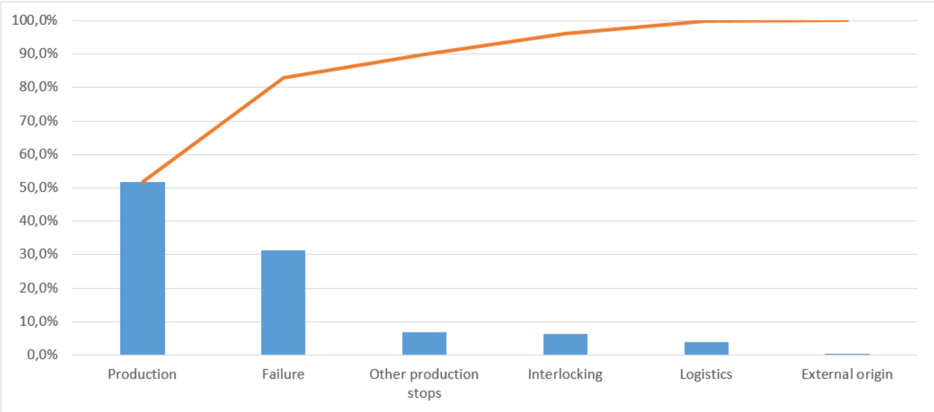

Figure 3.8: Total number of hours per stop

The product of the three indexes, results in an average OEE of 55%, being the monthly evolution of this parameter presented in figure 3.6 These values correspond to the overall effectiveness of the production unit 15. Improving the availability index without compromising performance and availability is the main goal.

3.4.6 Production Speed

The production speed is a very complex parameter, as it may be influenced by many factors such as the size of the box to be produced; the number of colours; the need for cutting; the size of the order; the orders’ amount; the number of stops, among others. According to these specifications, a standard goal value is set by the planning team. The operator is, however, responsible for setting the production speed and changing it over the order., This parameter is susceptible to the operator’s will. Thus, it is difficult to determine how a single parameter may influence speed, and subsequently be able to to improve it.

For example, the size of the box was, at first, pointed out by the operators as a great speed influence - when the board is bigger, the folding usually leads to problems and high speed may cause interlocking. However, the simple correlation between speed and box area is not significant (see table 3.1).

The three main “external” factors pointed out by the operators, namely 1) Box size, 2) downtime and 3) number of batch - were analyzed in order to better understand if the production speed curve and its peaks could be explained by external factors . The following table illustrates the correlation between them.

Table 3.1: Production speed correlation

Production speed vs box size	0.15
Production speed vs downtime	-0.89
Production speed vs number of orders	0.53

It can be concluded that from these three parameters analized, downtime plays the main influence. Downtime reflects a strong negative correlation with production speed. The value -0.89, close to one, indicates that the low values of production speed are related to the high values of downtime. In addiction, box size and number of orders have a weak positive correlation with production speed.

The figure 3.9 shows the average box size, by month, in the year of 2017.

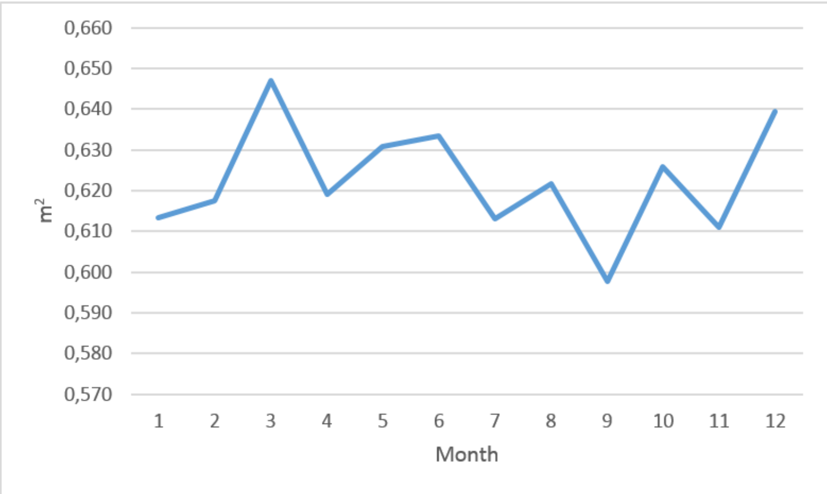

Figure 3.9: Average Box Size

One may conclude that that the size of the box does not deviate much from the average of 0.62 m^2 during the year. Nonetheless, it is also verified that in March the average size is 0.65 m^2, reaching a high peak in the graph, while, In contrast, in September the average size is 0.598m^2, represented by a lower peak in the chart.

Since the average box size remains approximately constant, this parameter will not explain the tendency of production speed curve. In fact, the observation of the box size and production speed curves does not show a similar behaviours.

The stop time stands as the main influence over production speed with the production speed decreasing with the rise of downtime. This fact is according to expectations since the machine has a boot time, and therefore cannot start at its maximum speed. Hence, a bigger stop time represents more stops and more (re)starts for the machine. Not always a bigger stop time is a synonym of an increased amount of stops.

The Production Speed of PU 15, in 2017, as illustrated in the figure 3.10, has been decreased. In fact, the average of the year is approximately 5000 sheets/h while the goal set for that year was about 6000 sheets/h.

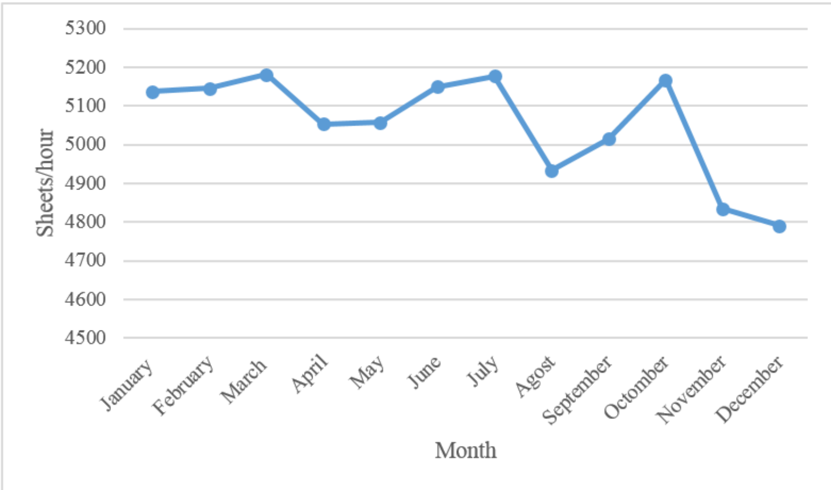

Figure 3.10: Production Speed PU15

3.4.7 Productivity

Productivity is the effectiveness of the output. In this particular case, the productivity is measured in square meters per hour because this . The indicators that may directly influence productivity are production speed, box size and downtime.

Table 3.2: Productivity correlation

Productivity vs box size	0.21
Productivity vs downtime	-0.82
Productivity vs production speed	0.81

The box size produced was analyzed, in order to understand if this parameter presents variations that might affect productivity. As aforementioned, the box size does not varies significantly. Although the curve on figure 3.9 seems to have a several ups and downs, the standard deviation is low (0.013 m^2), and it remains approximately constant over the year.

When it comes to production speed, as expected, the correlation is strong positive. When the production speed increases, the productivity increases. It is easily concluded that if the machine is working faster, it will produce more m^2 in shorter amount of time.

Regarding downtime, the correlation is also strong positive. The productivity is measured according to the working hours, not production hours, and when the machine has an unplanned stop the productivity registered is zero (see table 3.2).

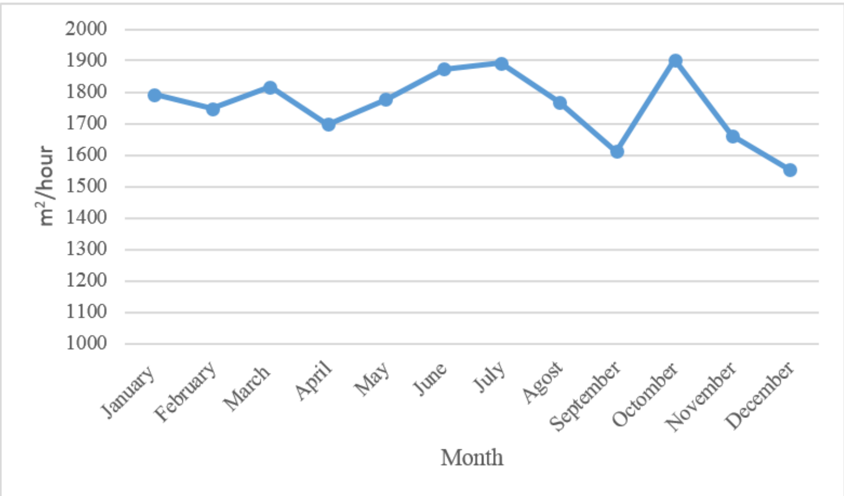

Figure 3.11: Productivity PU15

The figure 3.11 shows that there is a decreasing trend of the productivity of PU 15, in 2017, especially in the last trimester. This tendency can be explained by the production speed and downtime values.

The similarity between productivity curve and production speed curve is evident. It is also clear that the high peaks in downtime represent low peaks in productivity.

This parameter is measured in square meters per hour and the 2017 average stood at about 1800 m^2/h. The figure reveals a low productivity of 1612 m^2/h in September, resulting from an intensive increase of downtime, an increase in speed may be verified.

3.4.8 Shop floor environment

The organizational arrangement of the line follows almost a "U" format, that is, the beginning and the end of production are on the same side. This space organization is operator- "friendly" and brings about a number of advantages. All equipment and tools are located very close to one another, thus allowing the whole team to work almost simultaneously, while benefiting from communication and teamwork. The layout of the production line can be found in appendix A.4

3.4.8.1 5S

5S techniques were already implemented on the PU 15. Every month, a 5S audit takes place, and depending on its results, workers may or may not be rewarded with a prize. However, the results in the first trimester of 2018, were not the best. Aa time goes by, focus on these 5 rules evidently decreased.

The organization of the workspace is important since it allows better conditions and consequently an increase in productivity and quality. Thus, each workstation and its surrounding area were individually analyzed, and the points that need more organization and cleaning were identified . The three machines require tools which help the operators to perform the machine adjustment. However, these are scattered, not having a place of their own (fig. 3.13). As it is possible to verify in Fig. 3.12 the section shows pallets that are leaning against the machines and the micro coils are scattered in the hallways.

Figure 3.12: *Pallets Disposal*

Figure 3.13: *Tool Drawer*

3.4.9 Setup Time

Setup time is the time between the end of the last good product of the previous batch and the first good product of the new batch. It stands as the time needed to change tools and/ or to adjust the machine for the production of a different model. As previously stated , PU 15 has 4 printing corps and there is the possibility of adding a cutting. These characteristics add to this PU versatility and, as a consequence, a wide range of combinations is possible. Taking the two major changes into account - colour and cutting - ten types of reference may be identified:

Table 3.3 presents the symbol and each type's corresponding description.

Table 3.3: Reference types

Symbol	Label
0	without colour
1	one colour
2	two colours
3	three colours
4	four colours
0C	without colour, with cutting
1C	one colour, with cutting
2C	two colours, with cutting
3C	three colours, with cutting
4C	four colours, with cutting

In order to identify the existence of a tendency in terms of the types of references produced, data of all the processed orders in 2017 was collected and, a type of reference was attributed to each of them,. The following figure shows the number of times (y-axis) that the product type (on the x-axis) occurs, where each line represents one month of the year.

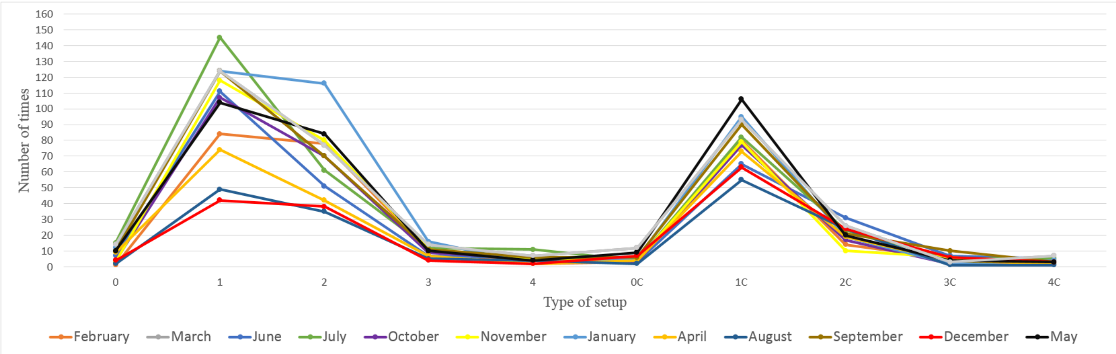

Figure 3.14: Reference Type Frequency

One may verify that the number of references of each type follows approximately the same curve in all months. It is also visible that the two curves with lower values take place in December and August, which correspond to the months where the production unit is stopped for vacations, which, as mentioned previously in this thesis, explains the decrease.

Nevertheless, the new reference to be produced is not enough for defining a setup. It was concluded that the previous reference makes a difference in the setup time and so the change of tool will take into account not only the next order but also the previous one. Since the number of setup types' combinations is very high (100), the idea was to find a pattern that would allow the combinations grouping according to the time of setup, creating six macro setup intervals.

With that purpose, the following setup matrix was designed (figure 3.15), with the rows representing the previous setup type and the columns the following. As an example, the first 0-0 square, means the change of a colorless and cutless order for an order with the same characteristics.

Each square shows the average setup time of the year of 2017 according to the setup type. A colour segregation was also made according to the time, with the aim of finding a pattern. However, as no pattern was identified, and it may only be noted that the use of cutting and of a greater number of colours means a higher setup times, as expected.

It is important to emphasize that these types of setups do not have the same frequency, a matrix with the frequency is presented in Appendix A.1. Some of them were not checked.

	0	1	2	3	4	0C	1C	2C	3C	4C
0	14	13	13	10		10	18	10	17	11
1	16	14	16	17	11	15	15	14	13	11
2	25	17	16	16	14	15	19	16	15	11
3	17	21	23	18	21	20	22	26	14	
4		22	30	34	35		35	21	24	40
0C		17	19	22	11	23	19	19	18	30
1C	17	18	19	18	16	19	18	20	17	22
2C	23	24	21	19	13	25	21	22	17	
3C	22	26	24	30	19		26	32	45	
4C		34	34		33		49	29	2	12

TIME
<10
10--12
12--14
14--16
16--18
18--20
20--22
22--24
24--26
>26

Figure 3.15: Setup Matrix

The calculated frequency demonstrated that the three most frequent types of setup are: 1-1, 1C-1C and 2-1 with, 17%, 12% and 10%, respectively. Besides these, the frequency of the other setups remained under 5% per year.

It is also important to point out that, for these setups, the time is considerably high. Taking as an example the setup 1-1, since it does not include cutting and it is a changeover commonly done, 14 min is not within the company goals interval.

In conclusion, the average type of all setups, by month, is presented in figure 3.16.

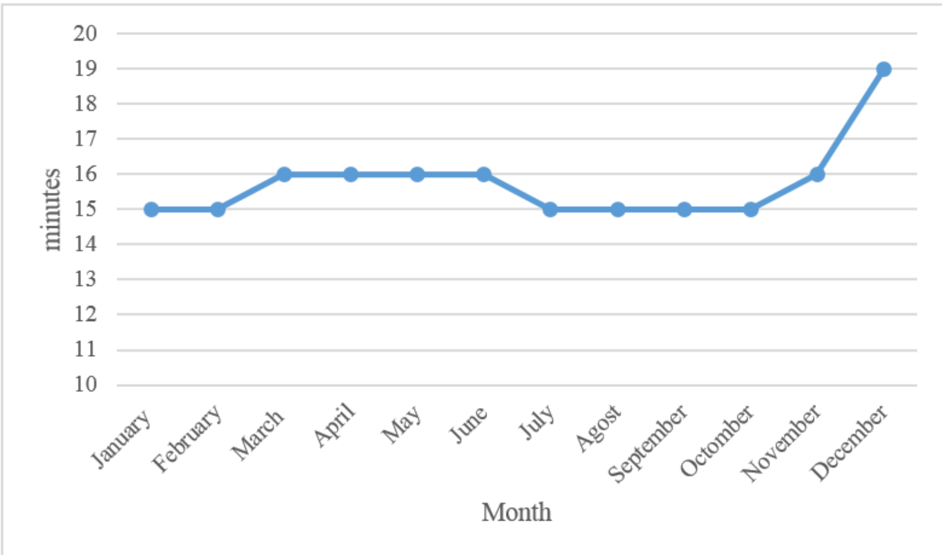

Figure 3.16: Setup Time PU15

3.4.9.1 Planning

Currently,when it comes to planning, what is being done is the preparation of pre assembles and its disposal in PU.

With regard to production planning, and in addition to the special care taken during the setup in order to minimize time, there are some rules that go along the same line, namely:

- Merge reference with color and reference without color. Try to put a reference without color after one with more colors or darker;
- Group colors that are the same or similar, going from lightest to darkest;
- Group by card type;
- Group references with extended tab;
- Group references with mold.

3.5 Conclusions

The main conclusions drawn by the initial analysis of PU 15 focus on Setup time. The low value of OEE is related to availability losses, and these are in turn related, in part, to high setup times. In fact, 61,4% of the availability losses are caused by setups.

Flexibility stands for the ability to adapt in terms of time, quantity and variety. Small batches increase flexibility. Along with setup time reduction, come increased operational flexibility; and decrease of bottlenecks, costs and lead time. In conclusion, an increase of the number of setups allows the reduction of batches; stocks; times; and leads to improved service quality and to raises in productivity and waste reduction.

The next chapter will focus on improving setups with the aim of reducing their time, in particular though the application of the SMED methodology.

Chapter 4

SMED Application

Setup activities include the operations of 1) tool changes, 2) processes and machine preparation, and 3) adjustments. Since setup time does not add value to the product, it might, from the customers' perspective, be considered waste. The SMED methodology to be implemented focuses on setup activities and in increasing their efficiency in order to reduce setup time and, consequently, to reduce waste.

4.1 Preliminary Stage

An initial analysis is very important in terms of obtaining a correct diagnosis, and subsequently in helping to understand which solutions may improve the systems' negative aspects. The results obtained at this stage are also relevant for assessing and comparing the impact of the adopted solutions. Thus, the first phases of analysis aimed at collecting the maximum information possible about setups, focusing on:

- The sequence of operations performed;
- The duration of different tasks and operations;
- Process aspects related to the operators, organization and equipment involved, among others;
- Identification of critical points that reduce the effectiveness of the production system, as well as their causes.

4.1.1 Tasks

A list of all activities that can be performed during a setup, along with the corresponding clarification, will be presented as follows. Moreover, according to its type, not all of the following activities may need to be executed during a setup.

- Document Verification: consists in checking the order sheet, identify the setup needed for the next order and verify the materials needed;
- Pre assemmblies Preparation : verify that the stamp and mold are in the pre-assembly car and if it corresponds to the standard made by the design office. With regard to the stamp, if necessary, introduce any specification required (for example: recycled symbol) and put adhesive tape over it, in order to fix it to the machine during the setup;
- Ink verification consists in verifying if the ink is in the pre-assembly car and if it corresponds to the one indicated in the standard. Furthermore, check viscosity and, if necessary, add additive, and place it closer it to the machine;
- End order in PC-Topp: introduce in the system the quantity referring to the last pallet and finalize order;
- Finish Palletization: as soon as the machine stops, there is a buffer of finished goods in the production line that must be palletized;
- Enter box format values, bridge setting and glue parameters. Introduce the values that are in the order sheet in the machine. In some cases, it is necessary to make some adjustments in the machine;
- Set to zero and open machine. This is automatic, through buttons but does require pressure during the process;
- Wash ink tank, when applicable. The task is automated. The machine cleans itself.
- Wash ink recipient, when applicable, manual wash the ink recipient (sometimes it is also necessary to use a special product, (located in the working table);
- Roller adjustment. According to the board dimension some measurements are done in order to adjust the length of the rollers;
- Remove stamps, when applicable. Remove the stamps and the tape from the machine and place them in the pre-assembly car;

- Place stamps in the machine, when applicable, lining up the center of the stamp with the center of the rollers;
- Remove mold, when applicable.
- Place mold, when applicable.
- Change stumps, when applicable. If the cardboard changes from simple to double, or vice versa, the stumps, disposed in the working table, require changing;
- Adjust pressure. In each module (4 printing module and 1 cut module), the pressure needs to be adjusted considering the cardboard and ink specifications. It does not have a standard value, the operator adjusts it taking his own experience into account;
- Packets and Stop adjustment. Introduce the number of boxes that will be bundled and adjust the size of the stop;
- Adjust feeder table to the correct size according to the board size;
- Adjust folding and output forks. Manual adjustment in the machine, when the size of the box is bigger;
- Close the machine;
- First Box Adjustment.

Some activities are dependent on others, as an example, prior to placing the mold, the previous one must to be removed. The rollers' adjustments cannot be performed at the same time as stamps are removed and placed in the same printing module. The same applies to the mold module.

The preliminary stage comprises the identification of all activities performed during a change of reference of PU15, according to the moment of execution, namely internal and external setup.

This stage includes the results from the observation of the production line. In order to collect data on all the activities that might possibly be related to the performance of any type of change, 18 SMED observations were carried out, in an attempt of encompassing all the above-mentioned types of change. A data collection in the workplace took place, trough time measurement with a stopwatch and by the filming the operations. Tasks times, as well as who performed it and in which sequence, were recorded.

It is important to add that that every setup is different, depending not only on the type of setup, but also on the team by which it is performed. Some differences between the different shifts were observed. During the observation phase, the operator of one of the teams was changed and that might be the cause for the time-related differences observed between shifts, and it will therefore, not be included in the analysis. The definition of a procedure is crucial for achieving similarity between all existing shifts. Further, the procedure executed by the different shifts will be explored, as a source of improvement.

The following table provides a segregation of setup tasks into internal or external according to their specific characteristics. It also indicates their respective average time, which was calculated over the course of the preparation of the SMED analysis.

Table 4.1: Setup Tasks

Task	Initial Situation	Time (mm:ss)	Precedence
1- Document Verification	EXTERNAL	4:00	-
2- Pre-assemblies Preparation	EXTERNAL	5:00	-
3- Ink Verification	EXTERNAL	1:30	-
4- End order in PC-Topp	INTERNAL	2:30	-
5- Finish Palletization	INTERNAL	4:00	-
6- Set to zero	INTERNAL	0:10	-
7- Open machine	INTERNAL	00:37	6
8- Enter box format values, bridge setting and glue parameters	INTERNAL	1:25	6
9- Adjust feeder table	INTERNAL	1:10	-
10- Ink Wash	INTERNAL	3:20	6,7
11- Wash ink recipient	INTERNAL	1:30	-
12- Roller adjustment	INTERNAL	1:54	6,7
13- Remove stamp	INTERNAL	00:53	6,7
14- Dispose stamp	INTERNAL	1:00	6,7,13
15- Remove mold	INTERNAL	1:09	6,7
16- Dispose mold	INTERNAL	1:40	6,7,15
17- Change stumps	INTERNAL	3:00	6,7
18- Adjust pressure	INTERNAL	1:10	6,7
19- Packets and Stop adjustment	INTERNAL	00:30	6
20- Adjust folding and output forks	INTERNAL	2:00	6,7
21- Close machine	INTERNAL	00:56	-
22- First Box adjustment	INTERNAL	3:30	-

4.2 First Stage

4.2.1 Workshop

In this phase, the collaboration of those who better understand how the PU 15 works and their setup activities was considered of the utmost importance. Therefore, a SMED workshop with the PU 15 operators and the shift managers, approaching the following topics, was organized:

- Theoretical Concepts review;
- Changeovers filming observation;
- Positive aspects;
- Negative aspects;
- Discussion on type of setup;
- Tasks distribution;
- Improvement suggestions.

A practical example of one of the most frequent setups (1C-1C) was analyzed in order to review the procedure linked to each team and to discuss possible improvements. The total setup time was 15 min, which in comparison with the average is considered good, but not yet satisfactory, since this setup should take less than 10 min. In fact, in this example there were no adjustments in the machine regarding the bridge and output forks.

As mentioned previously in chapter 3, the average time for a setup 1C-1C is approximately 18 minutes. This number is far below optimal since the setup is not very complex. Despite the need for a change of mold, there is only one color, and sometimes the color remains the same. Thus, this high value is not justifiable.

The initial internal teamwork organization is shown in the following picture 4.2.

In the initial situation there were no standard procedures related to the setup. The operator was responsible for assigning tasks to the assistants according to his experience. He would proceed to do this, while the machine was stopped. Thus, there was waste of time in communication.

Further, the operator could not assign just any task to just any assistant, due to the existing differences in their individual experiences and tasks training. This is the case

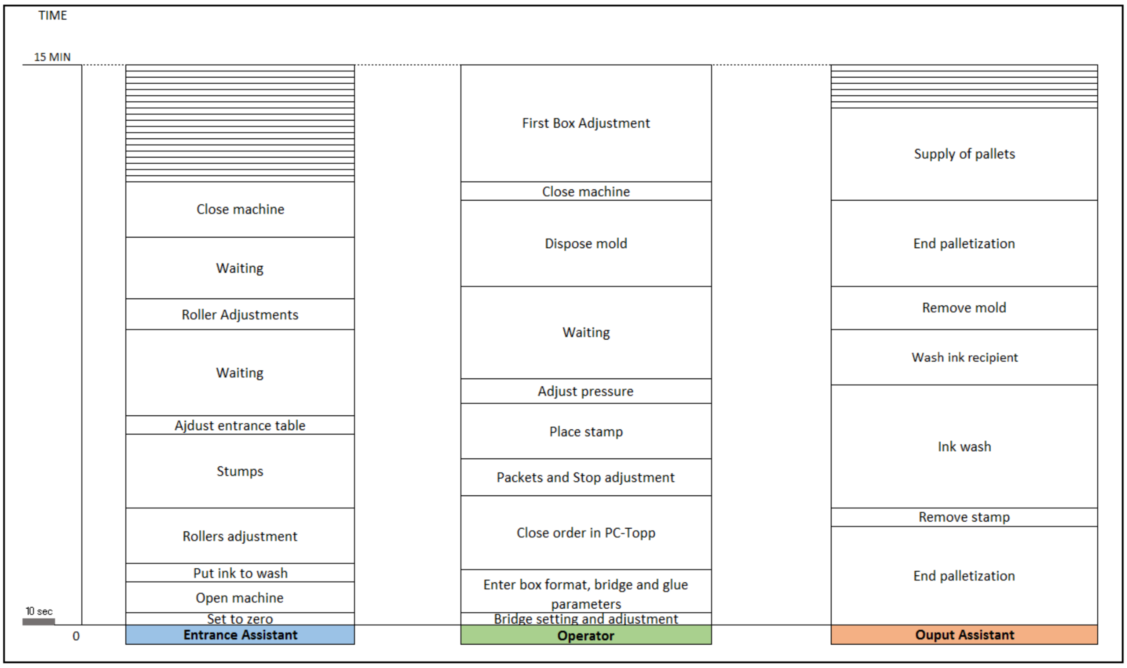

Figure 4.1: Setup 1C-1C Example

when placing stamps and molds, and when adjusting stumps and rollers. When the operator would have more experience and knowledge about the machine, he would opt for performing the most difficult tasks, accumulating therefore several of them of.

There were difficulties experienced due to coordination and space conflict. In fact, there were tasks which needed to be performed in the same area and sometimes the available space would not be enough to allow a simultaneous performance of those tasks.

Adjustments are considered to be very time-consuming tasks. In fact, adjustments would not be necessary if the parameters introduced were consistently correct and if the machine was well calibrated.

Apart from these setbacks, there are a few other aspects that may increase setup time. It can happen that the pre-assembly car is not at the workstation, which will cause delays in the setup. This may be due to logistics issues, such as a delay in supplying the PU, or a planning failure, that did therefore not allow the supply of the PU.

4.3 Second Stage

In the previous section, all tasks and the corresponding responsible person and time were identified. The second stage consists in converting, when possible, the internal setup into an external one. The table 4.2 presents a proposal for the classification of all tasks.

Table 4.2: Tasks Classification

Task	Initial Situation	Proposal
Document Verification	EXTERNAL	EXTERNAL
Pre-assemblies Preparation	EXTERNAL	EXTERNAL
Ink Verification	EXTERNAL	EXTERNAL
Finish Palletization	INTERNAL	**EXTERNAL**
End order in PC-Topp	INTERNAL	**EXTERNAL**
Set to zero and open machine	INTERNAL	INTERNAL
Enter box format values, bridge setting and glue parameters	INTERNAL	INTERNAL
Adjust entrance table	INTERNAL	INTERNAL
Ink Wash	INTERNAL	**EXTERNAL**
Wash ink recipient	INTERNAL	INTERNAL
Roller adjustment	INTERNAL	INTERNAL
Remove stamp	INTERNAL	INTERNAL
Dispose stamp	INTERNAL	INTERNAL
Remove mold	INTERNAL	INTERNAL
Dispose mold	INTERNAL	INTERNAL
Change stumps	INTERNAL	INTERNAL
Adjust pressure	INTERNAL	INTERNAL
Packets and Stop adjustment	INTERNAL	INTERNAL
Adjust folding and output forks	INTERNAL	INTERNAL
Close machine	INTERNAL	INTERNAL
First Box adjustment	INTERNAL	INTERNAL

The task "Finish palletization" may be converted into an external setup, for the most kind of setups, but this depends on the availability of the responsible worker - output assistant. Its time enables its conversion into external if it is executed at the beginning of the next order, where the exit carpet is still empty. The analysis done for types 11 and 1C-1C, concluded that such a conversion is indeed possible.

The task End of order in Pc-Topp does not need to be done exactly after the finishing of the order - it may be moved to an external setup. It is a simple procedure that can be done by the operator after the next order is started. So, this task may be moved to after the completion of the setup, while the new order is already under production.

Ink wash may also be converted into external setup, since the machine has the ability to wash the printing module while it is working without compromising the quality of the boxes. In the setup types that only include one color, this task can be moved to external, because one of the other three printing modules may be used, while the one used in the previous order is being washed.

4.4 Third Stage

The last stage of SMED is the simplification and improvement of the tasks. From the SMED analysis along with the discussion of setup during the workshop mentioned before, some problems were detected. Namely, the responsible for the task, the correlation between tasks and the cooperation during the setup.

One of the main problems identified in carrying out activities during the setup was related to their organization and sequencing.

Another problem identified was the correlation of the tasks. The tasks “remove” and “place pre-assembly” should be done successively and by the same worker. The same reasoning applies to the tasks “remove” and “place mold”. Cooperation between workers is very important. There were some differences between shifts in some tasks. Regarding the task “open the machine”, one shift performed it with only one worker (taking 45 sec) while another with 2 workers (taking 20 sec). In some cases, the opposite occurs. Two workers perform the same task unnecessarily, hence generating waste.

The sequencing and distribution of activities is not properly defined in form of an instruction. Tasks distribution is done by the operator in accordance with the experience of each assistant. Within each team, it was noted that there was no specific order in terms of preparation. The same task could be performed by several elements and these were very concentrated in the operator.

There is no clear distinction between processes and work order. Changeover process is optimal when both assistants have total availability and the performance of the setup is according to the standard. The unavailability identified in the previous stage was related to the exit assistant while performing the end of the palletization. However, this was converted in an external activity, thus it is no longer a problem. A definition of both 1) the sequence of the activities’ execution and 2) the worker who operates it, is expected to generate a better flow during the setup, since waste in communication is eliminated. Further, it is urgent to simplify activities, while prioritizing the internal type.

4.4.1 Maintenance Improvement Actions

Ink wash is a task that should be performed while the machine is operating, considering that the printer body is not being used. That is, if there is a printer body that has not been used and is washed, and one that is dirty and is not necessary at the moment, washing could be an external task. It turns out that as ink is denser than water, this procedure causes the water to go out and possibly compromise the proper functioning of that printing module. One solution figured together with maintenance would be to setup a flow regulator, which would allow a switching of this task to external. Thus, the placement of flow regulators in the printing bodies was defined as an improvement action.

Another problem identified with workers was the zero point of the machine. Under normal circumstances, the machine is able to set to zero automatically. However, possible failures may disable this option, forcing the worker to perform this resetting manually. This failure compromises the beginning of the setup activities, such as the introduction of parameters and the machine opening. Along with Maintenance, this problem was also set as an improvement action.

4.5 Proposed Solution

In this subchapter, and following the application of the SMED stages, a set of proposals for the execution of the setup types 1-1, 1C-1C, 1C-1 and 1-1C, that represent 42% of the total number of setups, will be presented.

These proposals highlight the importance 1) of a balanced distribution of tasks between operators; 2) of simultaneous performance and 3) of the training that should be provided in order to improve workers' performance.

The work was based on continuous improvement, always keeping in mind that there is also space for improvement through small daily changes. Nevertheless, the current average time collected on stage one will be used for a simulation of the average time of the tasks without the individual improvement mentioned on stage three. The new setups incorporated aspects such as converting internal into external activities, parallel performance, and cooperation between workers. It does not, however, take maintenance improvements into account. It was also created a standard work sheet and the correspondent spaghetti diagram for each solution. Normalization is a very important step to accomplish, because the lack of existence mean that there is no standard for the process and improving something that is not defined is much more complicated. The great diversity of products and consequently of existing procedures prevents the creation of a detailed work instruction that works for everyone. This will make possible to have similar setups in every type of reference and in any team, creating a linearity of data and decrease the deviation of values between them.

In order to implement these solutions, the next step would be the training of the operator and assistants so that all of them are able to perform any task and are conscious about the SMED methodology.

4.5.1 Setup 1C-1C

The following figure 4.2 presents the proposed setup for type 1C-1C. The new balancing of tasks was made assuming that the assistants have the ability to perform any task. Task time used is the average time calculated in Stage one.

Setups 1-1C, 1C-1 and 1C-1C can be considered twins. In fact, every time the mold is removed, if one is not needed, it is necessary to place trawl straps to guide the cardboard. These are similar to a mold, and their respective times of removal and disposal are also similar to the ones of a mold.

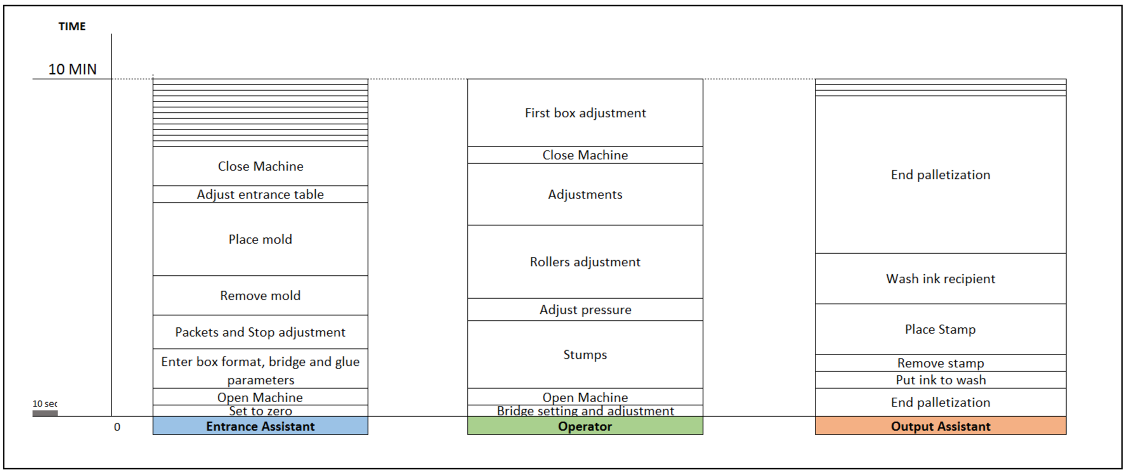

Figure 4.2: New Setup 1C-1C

For these reasons, these 3 setups have exactly the same tasks and can be projected the same way, as the figure 4.2 shows. The standard of these setups is presented in appendix A.5 and A.6.

According to the average time of the setups, the reduction expected was calculated and presented in the table 4.5.

Table 4.3: Reduction in setups 1C-1C, 1-1C and 1C-1

Setup	Average Setup time	New average setup time	Reduction
1C-1C	18	10	44%
1C-1	18	10	44%
1-1C	15	10	33%

4.5.2 Setup 1-1

Analogously to what was done before, the figure 4.3 shows the solutions for the setup 1-1. The standard of this setups is presented in appendix A.7 and A.8.

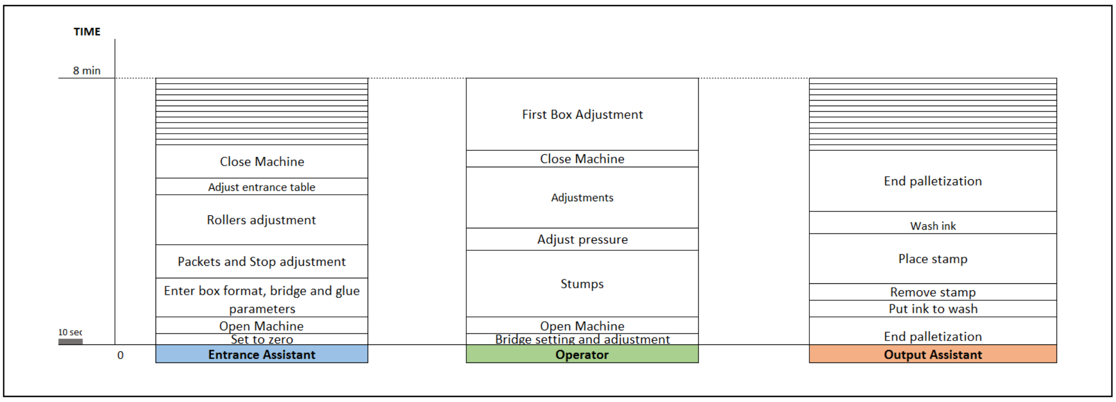

Figure 4.3: New Setup 1-1

Looking to the picture, seems that the operator accumulate more tasks than the assistants, increasing the setup time. However, the tasks responsible for it is the last one - First Box Adjustment - that has to be done after all the other ones and with the machine closed.

Table 4.4: Reduction in setup 1-1

Setup	Average Setup time	New average setup time	Reduction
1-1	14	8	43%

4.5.3 OEE improvement

As stated previously in this thesis, setups 1C-1C, 1-1, 1C-1 and 1-1C represent 42% of the total number of setups. Nonetheless, when it comes to total preparation time, setups 1C-1C e 1-1 represent 12.61%, 14.16% and 6.10% and 5.13% respectively, a total of 38% of the preparation time.

The OEE is thus going to be calculated according to the above-mentioned reference values and to the expected average reduction in these setups.

Table 4.5: Total setup reduction

Setup	% Preparation Time	% Reduction	Reduction in Preparation Time
1-1	14.16%	43%	6.08%
1C-1C	12.61%	44%	5.6%
1C-1	6.10%	44%	2.7%
1-1C	5.13%	33%	1.71%
TOTAL	38%	-	16.09%

With the proposed improvements, which include only these two types of setups, the expected reduction in the total preparation time is approximately 16.09%.

Considering one month,

- The average time of work = 331.09 hours;
- The average downtime = 51.86 hours;
- The average preparation time = 78.59 hours;
- New average preparation time = 65.95 hours.

Table 4.6: OEE Indexes

Index	Initial	Expected
Quality	99.11%	99.11%
Performance	92.06%	92.06%
Availability	60.55%	**64.42%**
OEE	55.24%	**58.77%**

The OEE sustains an increase of 3.5 pp (percentage points). This value represents a gain of 139 hours in a year (3.5% * Total number of working hours).

As the machine operates at full capacity (three shifts per day) Considering that the productivity is 1900 m^2/h and that the sales price is 400 per 1000 m^2, the increase in OEE would result in a sales increase of 105700 euros.

4.6 Results Discussion

Since a significant initial saving can be achieved in these typologies, a filter was run in the production monitoring program for the four orders and the average time during the period of the initial situation was calculated.

During the second stage it is apparent that existing tasks can have both according to the previous order and the following order. A increased focus on results requires the training of each and every operator, as well as the creation of standardized documents that allow a better understanding of the most appropriate way of working with each type of task. Whenever possible, operators should identify them clearly as external and act accordingly, since the biggest improvement potential lies on them, more specifically by completing them after the order is started or even before it is finished.

There are about 100 different types of total setups and a considerable part of them consists of preparations that are rarely performed, according to the survey. However, in order to focus the analysis, the most common were were filtered and studied. All preparations have common and non-common tasks, so the creation of standard documents becomes important for the operator to know for which they are primarily responsible.

The proposals presented were built taking into account that the harmony of the setups should be maintained, that is, that each worker is able to clearly identify his spectrum of activity. The operative method proposed in this project, establishes a momentary order and a correct assignment of tasks, which aims at achieving a reduction in time. It was also helpful to establish the simultaneous performance of tasks by the operators and for them to become aware of the importance of the machine being closed as soon as possible, postponing thus the tasks that can be performed with the machine open for a later stage.

Both individual training and the implementation of standardization become therefore clearly crucial for a successful implementation of the SMED methodology, and for its incorporation in the work culture as continuous practice.

Chapter 5

Conclusions and Future Work

The main objective of this thesis was to develop a process capable of reducing the preparation time of the Production Unit 15. It was studied the application of the SMED Methodology in a casemaker production line, which allowed to identify the root causes of the problem - very high setup time - and elaborate proposals to reduce it.

In this project are presented proposals to reduce the setup time only by proposing an order of execution of the tasks and assigning them, that is to say, without reducing individual task times (by, for example, eliminate adjustments). As a result of this organizing and performing work simultaneously, as well as through the conversion of the tasks that were previously performed with the machine stopped, to be executed with the machine running, it was possible to expect a significant reduction of times.

The setup analysis made clear that disorganization and task sequence play an important role in the high setup time. It is possible to conclude that improving the work method may result in significant improvements in setup times, and consequently in efficiency. The lack of organization, as well as the lack of information and procedures' standardization were the considered to be the main problems that lead to high setup times. The workers' lack of experience and their lack of knowledge about which best practices to incorporate during the setup create considerable waste. Workers showed a very positive attitude, with the desire and autonomy to change.

After the study developed, the expected results with the implementation were very satisfactory. It is concluded that, with internal set conversion into external, organizational improvements and the commitment of workers, it is possible to achieve major results without relevant financial investments.

The goal of this project was reduce setup time in 10%. With the implementation of the proposals in setups 1-1, 1C-1, 1C-1 and 1C-1C, is expected a reduction of 16.09 % of the total preparation time, that, in turn, will increase OEE in 3.5pp, that reflects a potential raise in sales of, approximately, 105700 euros.

This dissertation project revealed that, in order to successfully apply a continuous improvement project, the theoretical knowledge is not enough. It is important to have communication and leadership skills and human relation. Develop these capabilities allowed to carry out a better survey of the situation, without having the focus on the responsible for error but rather in the path to overcome it. It was important to start changing the mentality of people who are accustomed to their work habits and communication in both directions. The operators eventually developed a most open and critical spirit in the development of their work, thereby for the validity and future success of the implementation of the proposals presented.

The future work includes the approval of the proposed solution and their implementation. In order to do that, the next step would be the training of the operator and assistants so that all of them are able to perform any task and are conscious about the SMED methodology.

Furthermore, this project allowed the elaboration of proposals of the operative way for the most frequent setups. As there are many types of different preparations it is important for future work to analyze other types of setups, in order to improve them.

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Appendix A

Appendix

A.1 Frequency Matrix

	0	1	2	3	4	0C	1C	2C	3C	4C
0	0,6%	1,1%	0,3%	0,1%	0,0%	0,0%	0,2%	0,1%	0,0%	0,1%
1	1,0%	17%	5,3%	0,9%	0,3%	0,6%	6,0%	1,2%	0,3%	0,1%
2	0,3%	5,1%	10%	0,9%	0,1%	0,2%	3,5%	1,1%	0,2%	0,1%
3	0,1%	0,9%	0,9%	0,2%	0,0%	0,1%	0,7%	0,2%	0,1%	0,0%
4	0,0%	0,3%	0,2%	0,1%	0,5%	0,0%	0,1%	0,1%	0,0%	0,3%
0C	0,0%	0,3%	0,1%	0,1%	0,0%	0,2%	0,7%	0,1%	0,0%	0,0%
1C	0,4%	5,9%	3,6%	0,6%	0,3%	0,5%	12%	2,1%	0,4%	0,3%
2C	0,2%	1,5%	1,0%	0,2%	0,1%	0,1%	2,0%	1,6%	0,2%	0,0%
3C	0,0%	0,3%	0,1%	0,1%	0,0%	0,0%	0,5%	0,2%	0,2%	0,0%
4C	0,0%	0,2%	0,1%	0,0%	0,2%	0,0%	0,2%	0,1%	0,0%	0,2%

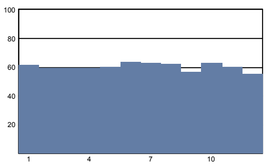
A.2 Overall Equipment Efficiency Report

Overall Equipment Efficiency Report — efi PC-Topp

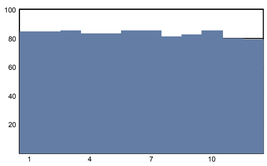
UP15 CASEMAKER 15 — Velocidade objectivo: 6000 — **2017**

Mês	Horas abertura	Interv.	Horas trabalho	Paragens Horas	Paragens %	Prep.	Stop Hours	Run Hours	Produção[2] pl.	Produção[2] pl / h	Desp. pl.	Desp. %	Ø Order Size m² / sht.	Ø Order Size pl.	Ø Order Size m²	Ø Order Size No. Out	Preparação No.	Preparação Ø h	OEE (Overall Equipment Efficiency)[1] Disponib.	Desempenho[3]	Qualidade	OEE
1	399'35	7'46	391'49	52'04	13,0 %	97'48	157'38	241'57	1,229,236	5,081	13,582	1,1 %	0,57	3,112	1,758	1.00	395	0'15	61,8 %	93,5 %	98,9 %	57,1 %
2	311'43	10'57	300'46	49'58	16,0 %	72'12	133'07	178'36	910,987	5,101	7,965	0,9 %	0,57	3,254	1,860	1.00	280	0'15	59,4 %	93,7 %	99,1 %	55,2 %
3	388'19	8'24	379'55	54'49	14,1 %	97'32	160'45	227'34	1,164,694	5,118	14,398	1,2 %	0,59	3,089	1,810	1.00	377	0'16	59,9 %	94,3 %	98,8 %	55,8 %
4	281'02	6'55	274'07	48'13	17,2 %	62'30	117'38	163'24	818,099	5,007	7,531	0,9 %	0,56	3,467	1,953	1.00	236	0'16	59,6 %	92,0 %	99,1 %	54,3 %
5	386'26	7'43	378'43	56'43	14,7 %	94'22	158'48	227'38	1,140,400	5,010	10,836	0,9 %	0,58	3,212	1,877	1.00	355	0'16	60,1 %	92,3 %	99,1 %	54,9 %
6	324'10	10'02	314'08	37'23	11,5 %	76'46	124'11	199'59	1,023,885	5,120	6,029	0,6 %	0,57	3,494	1,996	1.00	293	0'16	63,7 %	94,0 %	99,4 %	59,5 %
7	410'16	14'37	395'39	55'29	13,5 %	91'03	161'09	249'07	1,279,343	5,136	10,315	0,8 %	0,58	3,524	2,046	1.00	363	0'15	63,0 %	94,2 %	99,2 %	58,9 %
8	219'03	7'16	211'47	33'22	15,2 %	45'50	86'28	132'35	647,008	4,880	7,170	1,1 %	0,57	3,635	2,080	1.00	178	0'15	62,6 %	90,0 %	98,9 %	55,7 %
9	380'18	10'30	369'48	73'21	19,3 %	85'55	169'46	210'32	1,046,600	4,971	9,136	0,9 %	0,56	2,973	1,679	1.00	352	0'15	56,9 %	91,4 %	99,1 %	51,6 %
10	343'43	9'55	333'48	46'35	13,6 %	75'43	132'13	211'30	1,085,580	5,133	7,426	0,7 %	0,58	3,668	2,130	1.00	296	0'15	63,4 %	94,1 %	99,3 %	59,2 %
11	384'59	9'29	375'30	64'44	16,8 %	83'19	157'32	227'27	1,090,424	4,794	8,962	0,8 %	0,57	3,418	1,940	1.00	319	0'16	60,6 %	88,1 %	99,2 %	52,9 %
12	252'37	5'35	247'02	49'39	19,7 %	60'05	115'19	137'18	650,789	4,740	5,499	0,8 %	0,58	3,372	1,956	1.00	193	0'19	55,6 %	87,1 %	99,2 %	48,0 %
Total	**4082'11**	**109'09**	**3973'02**	**622'20**	**15,2 %**	**943'05**	**1674'34**	**2407'37**	**12,087,045**	**5,020**	**108,849**	**0,9 %**	**0.57**	**3,323**	**1,908**	**1.00**	**3637**	**0'16**	**60,6 %**	**92,3 %**	**99,1 %**	**55,4 %**
Ø	**340'10**	**9'05**	**331'05**	**51'51**		**78'35**	**139'32**	**200'38**	**1,007,254**		**9,071**						**303.1**					

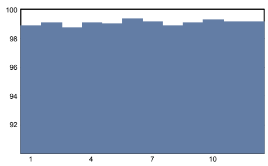
Disponiblidade (in %)



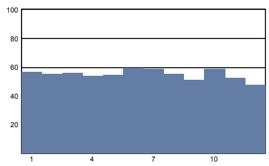
Performance (in %)



Quality (in %)



OEE (in %)



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A.3 Downtime analysis

Resumo de paragens — efi PC-Topp

UP15 CASEMAKER 15 — Todos os turnos / Todas as equipas — **2017**

Horas abertura	4082'11	Mini-paragens	113'41	2,9%
Intervalos	109'09	Horas paragem	508'39	12,8%
Horas trabalho	3973'02	Horas produção	3350'42	84,3%

No.	Causa	Dur. Total	Ø	HT 3973'02	HP 622'20	Order Related	Machine Related	Operat. Related	Not Def.
	Breakdowns								
317	Av.Atadeira	47'18	0'09	1,2%	7,6%				47'18
62	Av.U.Impressoras	25'16	0'24	0,6%	4,1%				25'16
31	Av.Slotter	23'30	0'45	0,6%	3,8%				23'30
50	Av.Saida Maquina	10'32	0'13	0,3%	1,7%				10'32
28	Av.Introductor	6'14	0'13	0,2%	1,0%				6'14
3	Av.Quadro Electrico	1'11	0'24	0,0%	0,2%				1'11
2	Av.Ar comprimido	0'27	0'14	0,0%	0,1%				0'27
2	Av.Rede Desperdicio	0'20	0'10	0,0%	0,1%				0'20
3	Av.U.Colagem/Agrafagem	0'18	0'06	0,0%	0,0%				0'18
1	Av.U.Dobradora	0'09	0'09	0,0%	0,0%				0'09
1	Av.Paletizador	0'05	0'05	0,0%	0,0%				0'05
1	Av.Linha Final Transformaçao	0'03	0'03	0,0%	0,0%				0'03
501	**AVARIA**	**115'23**	**0'14**	**2,9%**	**18,5%**				**115'23**
27	CTV - Erro Especificaçao Produto	9'10	0'20	0,2%	1,5%				9'10
22	Defeito Tinta/Cor	4'09	0'11	0,1%	0,7%				4'09
12	Defeito Pre-Montagem	2'50	0'14	0,1%	0,5%				2'50
3	Falta Pre-Montagem	1'27	0'29	0,0%	0,2%				1'27
6	Reparaçao Molde	1'01	0'10	0,0%	0,2%				1'01
5	Falta Tinta	1'00	0'12	0,0%	0,2%				1'00
1	Falta/Defeito Outros Mat.	0'33	0'33	0,0%	0,1%				0'33
3	Defeito Molde	0'30	0'10	0,0%	0,1%				0'30
1	Falta Molde	0'06	0'06	0,0%	0,0%				0'06
80	**LOGÍSTICA**	**20'46**	**0'16**	**0,5%**	**3,3%**				**20'46**
742	Outros encravamentos	98'15	0'08	2,5%	15,8%				98'15
841	Carimbo Sujo/Contaminado	69'33	0'05	1,8%	11,2%				69'33
204	Arranque	42'30	0'13	1,1%	6,8%				42'30
353	Problemas Cartao	38'16	0'07	1,0%	6,1%				38'16
59	Falta Cartao	16'40	0'17	0,4%	2,7%				16'40
94	Falta Escoamento Prod.Acabado	7'33	0'05	0,2%	1,2%				7'33
47	Outras Paragens de Processo	6'40	0'09	0,2%	1,1%				6'40
9	Mudar paletes (caixas prontas)	2'24	0'16	0,1%	0,4%				2'24
12	Erro Operaçao - Molde	1'33	0'08	0,0%	0,2%				1'33
4	Erro Operaçao - Impressao	0'38	0'10	0,0%	0,1%				0'38
3	Erro Operaçao - Varios	0'36	0'12	0,0%	0,1%				0'36
2368	**PRODUÇÃO**	**284'38**	**0'07**	**7,2%**	**45,7%**				**284'38**
154	Troca de Bobine da Cintadeira	14'09	0'06	0,4%	2,3%				14'09
34	Tinta Derramada	11'12	0'20	0,3%	1,8%				11'12
44	Troca de corpos impressores	7'35	0'10	0,2%	1,2%				7'35
10	Tapetes desperdício obstruído	3'03	0'18	0,1%	0,5%				3'03
242	**Outras paragens Produção**	**35'59**	**0'09**	**0,9%**	**5,8%**				**35'59**
330	encravamento correias da saida	29'31	0'05	0,7%	4,7%				29'31
96	outros encravamentos	22'18	0'14	0,6%	3,6%				22'18
1	encravamento empilhador saida	0'04	0'04	0,0%	0,0%				0'04
427	**Encravamento**	**51'53**	**0'07**	**1,3%**	**8,3%**				**51'53**
1106	Mini-paragens 1 min	18'26	0'01	0,5%	3,0%				18'26
1582	Mini-paragens 2 min	52'44	0'02	1,3%	8,5%				52'44
540	Mini-paragens 3 min	27'00	0'03	0,7%	4,3%				27'00
2	Mini-paragens 4 min	0'08	0'04	0,0%	0,0%				0'08
1	Mini-paragens 5 min	0'05	0'05	0,0%	0,0%				0'05
1	Mini-paragens 6 min	0'06	0'06	0,0%	0,0%				0'06
41	Times Unaccounted For	15'13	0'22	0,4%	2,4%				15'13
3273	**Total mini-paragens**	**113'42**	**0'02**	**2,9%**	**18,3%**				**113'42**

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Resumo de paragens PC-Topp

UP15 CASEMAKER 15 — Todos os turnos, Todas as equipas — **2017**

Horas abertura	4082'11	Mini-paragens	113'41	2,9%
Intervalos	109'09	Horas paragem	508'39	12,8%
Horas trabalho	3973'02	Horas produção	3350'42	84,3%

No.	Causa	Dur. Total	Ø	HT 3973'02	HP 622'20	Order Related	Machine Related	Operat. Related	Not Def.
Paragens programadas									
240	Limpeza Fim de Trabalho	91'35	0'23						91'35
8	Manutenção Preventiva	16'26	2'03						16'26
7	Testes	0'38	0'05						0'38
255	**PROGRAMADAS**	**108'39**	**0'26**						**108'39**
7146	Total paragens	731'00	0'06	18,4%	100,0%				731'00

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A.4 Production Unit 15 Layout

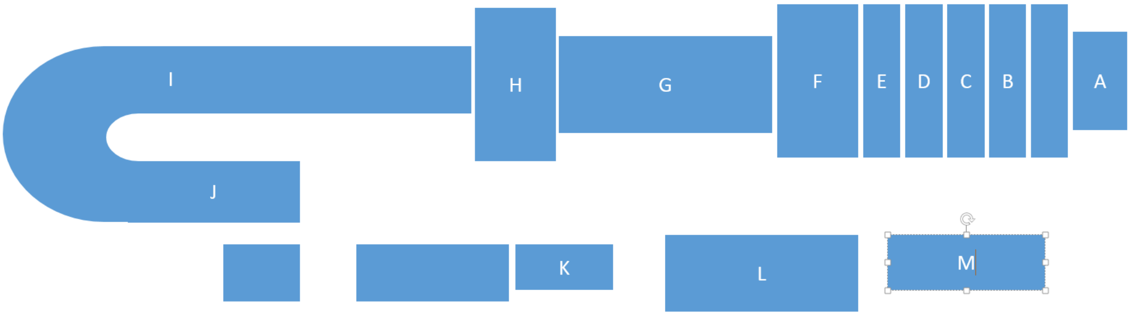
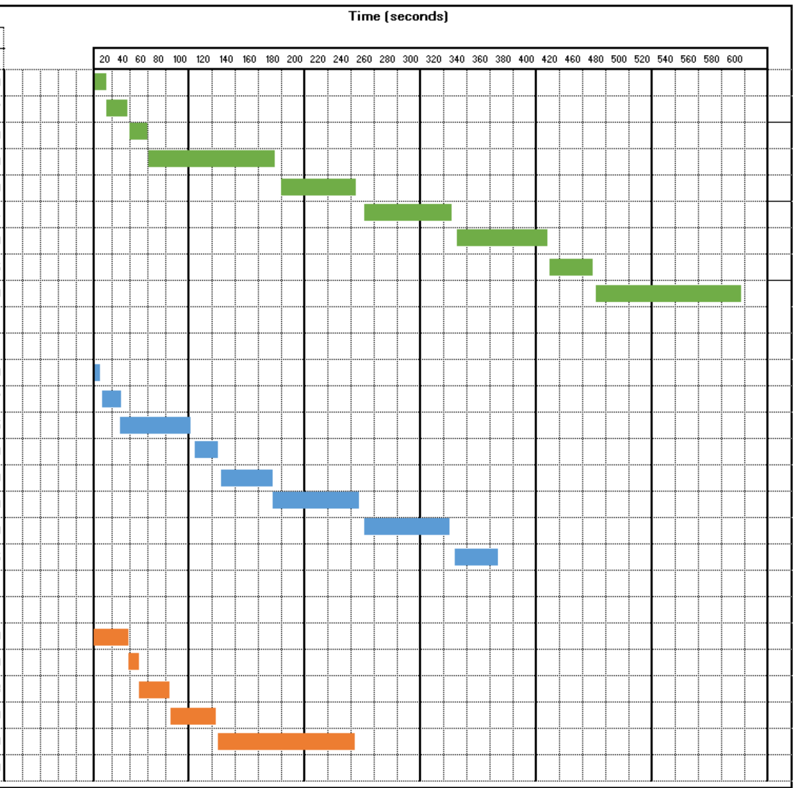


Table A.1: Layout Label

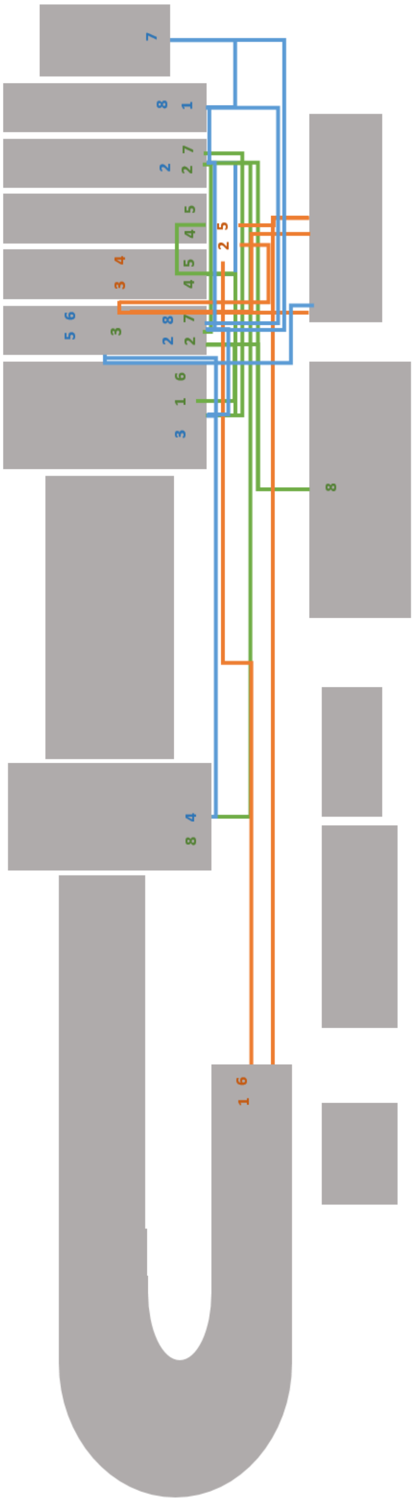
Symbol	Module
A	Feeding Table
B,C,D,E	Printing modules
F	Cutting module
G	Folding bridge
H	Stop and Ventilation Table
I	Wrapper
J	Palletization
K	Waste car
L	Work Table
M	Pre-assemblies car

A.5 Proposed Standard Work Combination Sheet: Setup 1C-1C

.	Description of Operation Step	Time seconds
	Operator	
1	Bridge setting and adjustments	90
2	Open machine	37
3	Tied setting and adjustment	30
4	Change stumps	180
5	Adjust pressure	70
6	Rollers adjustment	114
7	Adjustments	120
8	Close Machine	56
9	Fisrt Box Adjustment	210
	Entrance assistant	
1	Set to zero	10
2	Open Machine	37
3	Enter box format and glue parameters	65
4	Packets and Stop Adjustment	30
5	Remove mold	69
6	Place mold	100
7	Adjust feeder table	70
8	Close machine	56
	Output Assistant	
1	End palletization	60
2	Put ink to wash	20
3	Remove stamp	53
4	Place stamp	60
5	Wash ink tank	90
6	End palletization	180

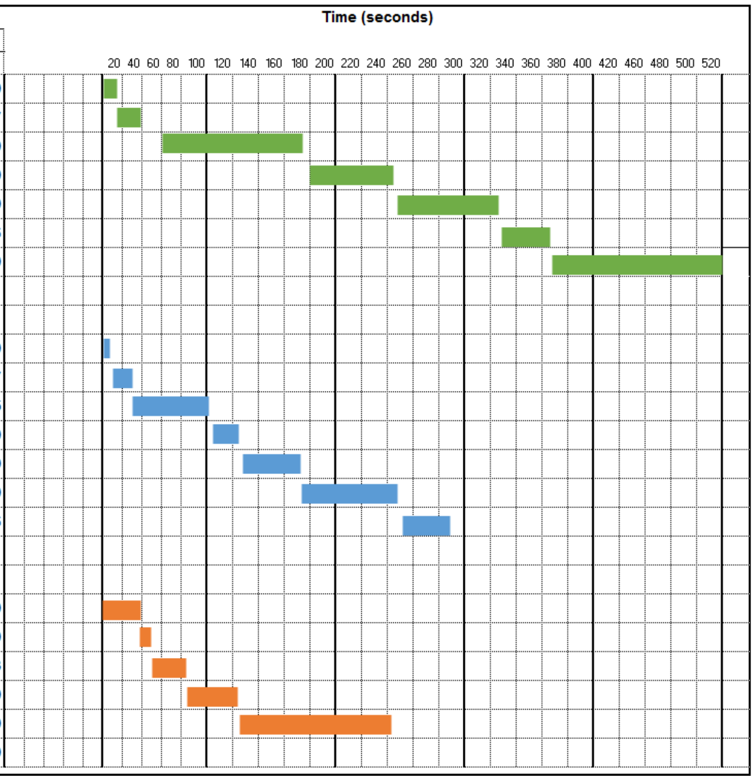


A.6 Proposed Spaghetti Diagram: Setup 1C-1C



A.7 Proposed Standard Work Combination Sheet: Setup 1-1

	Description of Operation Step	Time seconds
	Operator	
1	Bridge setting and adjustments	90
2	Open machine	37
4	Change stumps	180
5	Adjust pressure	70
7	Adjustments	120
8	Close Machine	56
9	Fisrt Box Adjustment	210
	Entrance assistant	
1	Set to zero	10
2	Open Machine	37
3	Enter box format and glue parameters	65
4	Packets and Stop Adjustment	30
5	Rollers adjustment	69
6	Adjust feeder table	70
8	Close machine	56
	Output Assistant	
1	End palletization	60
2	Put ink to wash	20
3	Remove stamp	53
4	Place stamp	60
5	Wash ink tank	90
6	End palletization	180



A.8 Proposed Spaghetti Diagram: Setup 1-1